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LANDFILL GAS GENERATION AND EMISSION AT DANISH WASTE DISPOSAL SITES RECEIVING WASTE WITH A LOW ORGANIC WASTE CONTENT

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SUMMARY: The landfill gas (LFG) generation from four Danish landfills was estimated using three first-order-decay (FOD) models; the LandGEM model (developed by the US EPA), the IPCC (developed by the Intergovernmental Panel on Climate Change) and the Afvalzorg model (developed by a Dutch company). The last two models are multi-phase models, which defines waste fractions into traditional MSW and low-organic waste categories, respectively. Both the LandGEM and the IPCC model estimated significantly larger methane (CH_4) generation in comparison to the Afvalzorg model. The Afvalzorg model could better show the influence of not only the total disposed waste amount, but also various waste categories, and was found more suitable to estimate LFG generation from landfills receiving low-organic waste. Four major waste categories currently being disposed at Danish landfills (mixed bulky, shredder, dewatered sludge and street cleansing waste) and temporarily stored combustible waste were sampled and characterized in terms of TS, VS, TC, TOC, and biochemical methane potential (BMP). Decay rates (k values), were determined by conducting anaerobic degradation experiments and applying FOD equations to the experimental results. The LFG generation from four Danish landfills was estimated by the Afvalzorg model using the experimentally based BMP and k values and compared to whole landfill emission rates measured by applying a tracer gas dispersion method. The results showed that the revised modelled LFG generation rates were in good agreement with field emission measurements, indicating that the revised model with site-specific data could provide a practical and accurate estimation of LFG emissions.

1. INTRODUCTION AND OBJECTIVE

Waste degradation at landfills is one of the major anthropogenic sources of methane (CH_4) generation and emissions in the world (Bogner et al., 2008). According to the EU Council Directive 1999/31/EC on the landfilling of waste, landfilling in Europe is limited to inert materials, which are not biodegradable or combustible (waste not containing significant fractions of organic matter) (EU, 1999; 2002). Consequently, more and more EU member states (for example the Netherlands as of 1996, Denmark as of 1997, and Germany as of 2005) have banned landfilling of organic waste. Although most currently disposed waste has low-organic contents, previous studies have shown significant CH_4 emissions at Danish landfills (Scheutz et al., 2011).

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According to the European Pollutants Release and Transfer Registers (E-PRTR) Regulation 166/2006/EC, operators of landfills with a total capacity of 25,000 ton or receiving more than 10 ton per day must quantify and report their pollutant emissions to the general public and their national government (CEC, 2006). Therefore it is important for landfill operators to have a reliable guideline to measure, calculate and estimate landfill gas (LFG) emissions for the E-PRTR reporting. Due to difficulties in precisely monitoring a whole site's CH_4 emissions, first order decay (FOD) landfill gas generation models are currently widely used to estimate CH_4 emissions from landfills. FOD models are recommended by both researchers and state regulators for estimating CH_4 generation from waste degradation. Most of the models are based on two primary parameters; a biochemical CH_4 potential (BMP) and an FOD rate constant (k) of the landfilled material. However, the BMP and FOD default values provided by most models are based on traditional municipal solid waste (MSW) fractions and the models are therefore not appropriate for modelling gas generation from landfills receiving waste with a low organic content.

The overall objective of this research project was to study CH_4 generation from low-organic waste disposed at Danish landfills and to provide new guidelines for estimating CH_4 emission from modern landfills to report to the E-PRTR. In this research, four categories of waste (street cleansing, mixed bulky, shredder, and sludge waste) with a low-organic content and temporarily stored combustible waste were sampled from four Danish landfills and characterized in the lab (Mou et al., 2014). BMP and k values of all sampled waste were quantified (Mou et al., 2015a). By applying site-specific data, CH_4 generation and emission estimated by original and revised FOD models were evaluated and compared (Mou et al., 2015b). Field CH_4 emission measurements using a tracer dispersion method of four Danish landfills were used to test the applicability of the revised Afvalzorg model. The oral presentation and proceeding paper provide an overview of the conclusions of a four year PhD project conducted at Technical University of Denmark (Mou, 2014).

2. COMPARISON OF LANDFILL GAS GENERATION MODELS

This study reviewed several currently used FOD LFG models in terms of their default parameter values and defined waste categories. Depending on whether various k values were defined for different waste categories, there are two kinds of models: multi- and single-phase FOD models. The single-phase model has no function for distinguishing various decay rates between different waste categories. The multiphase model required waste amount by fractions as input data. Three FOD models were selected to estimate LFG generation from Danish landfills. The single-phase LandGEM model was developed by the US EPA and was intended to model the LFG generation from traditional MSW disposal sites with relative homogeneous waste fractions. The IPCC (developed by the Intergovernmental Panel on Climate Change) and the Afvalzorg (developed by a Dutch company) models are multi-phase models, which define waste fractions into traditional MSW and low-organic waste categories, respectively. For running the models, actual waste data from four Danish landfills (AV Miljø, Audebo, Glatved, and Odense) were used as input data. Most disposed waste at Danish landfills had insignificant or very low organic fractions. Original waste data were translated into various waste fractions defined in the multi-phase models. By applying default values for the BMPs and k values, the annual and normalized CH_4 generation (kg CH_4 ton^{-1} waste) from the beginning of disposal until year 2020 and year 2100 at the four landfills were estimated by the three FOD models (using both default and revised parameter values). Figure 1 shows the annual CH_4 generation rates as functions of time at the four landfills. In comparison to the multi-phase model outcomes, the LandGEM model estimated significantly larger CH_4 generation because it defined only one relatively high BMP value (122 CH_4 ton^{-1} waste, wet weight) for low-organic waste. The IPCC model estimated only 25 to 33% of the annual CH_4 generation estimated by the LandGEM model until year 2020. The Afvalzorg model estimated only approximately 10% of the annual CH_4 generation estimated by the LandGEM model. Moreover, in comparison to the IPCC model, the Afvalzorg model could better show the influence of not only the total disposed waste amount, but also various waste categories. Therefore, the Afvalzorg model was found more suitable to estimate LFG generation from landfills receiving low-organic waste.

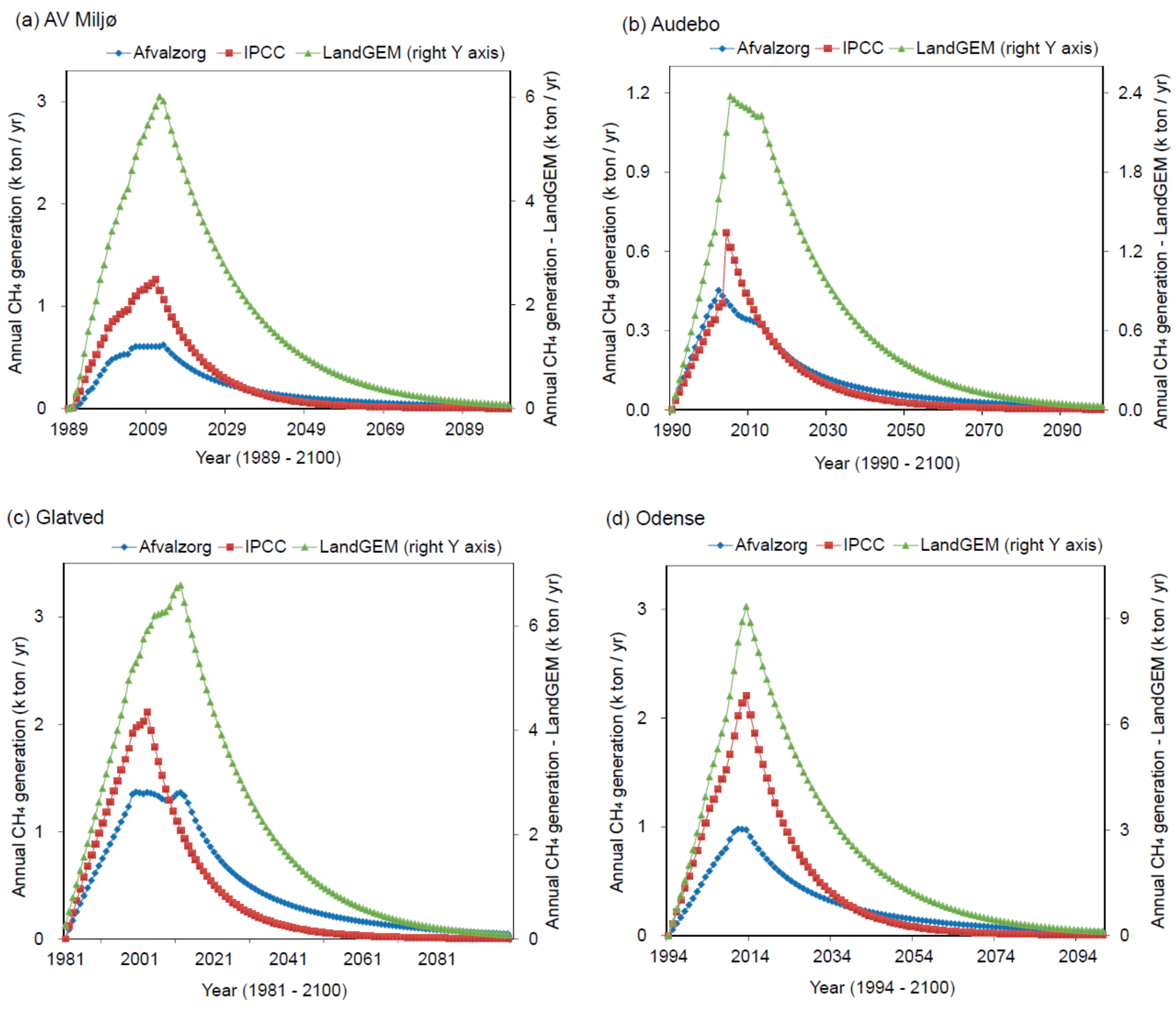

Figure 1. Annual CH4 generation rates as functions of time at the (a) AV Miljø; (b) Audebo; (c) Glatved; and d) Odense landfill, estimated by the original Afvalzorg, IPCC and LandGEM models with default parameter values (the right Y axis only applies to the LandGEM curve in all four figures) (Mou et al., 2014).

3. DETERMINATION OF BMP AND k VALUES

To further calibrate the BMPs and k values of Danish waste fractions, four major disposed waste categories (mixed bulky, shredder, dewatered sludge and street cleansing waste) and temporarily stored combustible waste were sampled and characterized in terms of TS, VS, TC, and TOC. In general, waste samples showed lower TOC contents than traditional MSW fractions. The same category of waste samples from different landfills showed similar results. By incubation experiments at 55 ^{o}C over 77 days, the BMPs of all waste samples were determined. As main fractions at Danish landfills, mixed bulky and shredder waste had similar BMPs, which was in the range of 5.4-9.1 kg CH_4 ton^{-1} waste (wet weight) on average. The sludge waste and temporarily stored combustible waste showed BMP values of 51.8-69.6 and 106.6-117.3 kg CH_4 ton^{-1} waste on average, respectively. For determining k values, anaerobic degradation experiments were set up in duplicate and incubated for 405 days, during which the cumulative CH_4 generation was continuously monitored. Applying FOD equations to the experimental results, k values of all waste samples were determined. Likewise, similar waste categories obtained from different Danish landfills showed similar results. Sludge waste had the highest k values, which were in the range 0.156-0.189 yr^{-1}. The combustible and street cleansing waste showed k values of 0.023-0.027 yr^{-1} and 0.073-0.083 yr^{-1}, respectively. The lowest k values were obtained for mixed bulky and shredder wastes ranging from 0.013 to 0.017 yr^{-1}. Most low-organic waste samples showed lower BMPs and k values in comparison to the default numeric values in current FOD models.

4. METHANE GENERATION AND EMISSION RATES

By using lab-determined results, the Afvalzorg model was revised and estimated smaller cumulative CH_4 generation results in comparison to running the model with default values (Figure 2). Based on CH_4 recovery data (provided by the landfill operators) and estimated CH_4 oxidation factor of 10%, fugitive CH_4 emissions from whole-sites and a specific cell for shredder waste at the Odense landfill were aggregated based on the revised Afvalzorg model outcomes. Former studies have established a tracer dispersion method as a reliable and accurate approach for quantifying whole-site fugitive landfill CH_4 emissions, which were applied at the same landfills (Mønster et al, 2014). Aggregated CH_4 emissions were in good agreement with field measurements (Figure 3), indicating that the revised FOD model with site-specific data could provide a practical and accurate estimation for LFG emissions. Additionally, by using only one k value for each waste category instead of identifying various degradable fractions, the Afvalzorg model could be revised as a less complicated and more practical model for the Danish scenario.

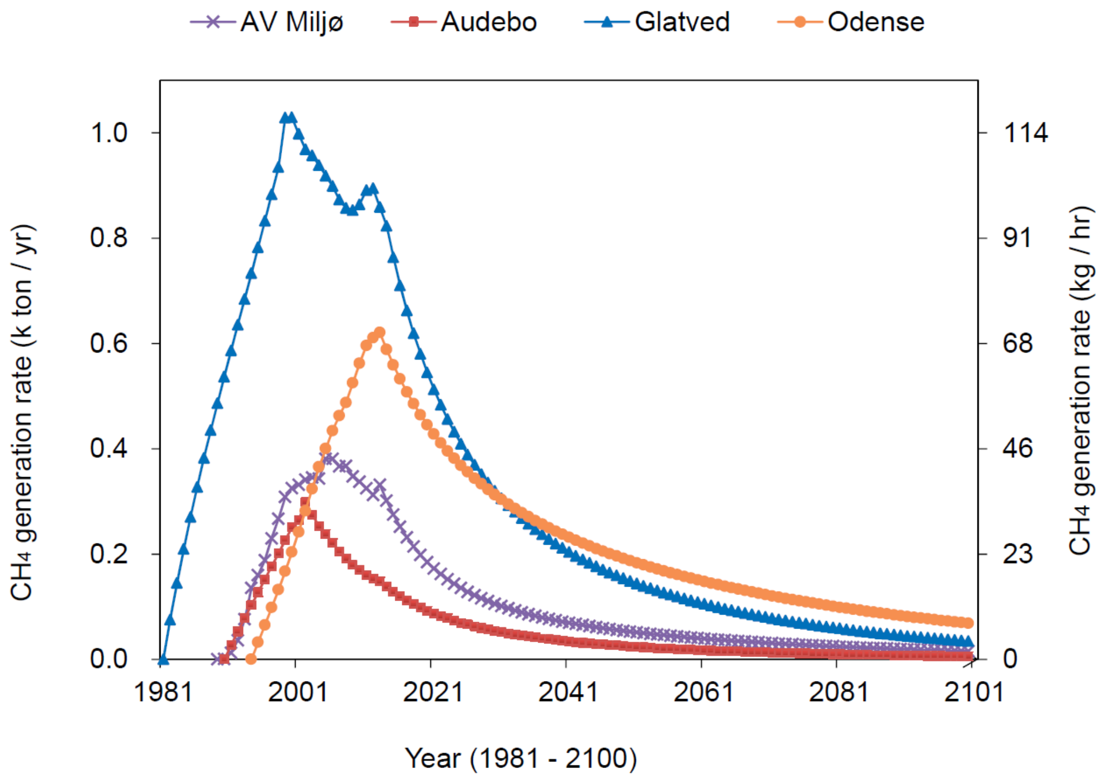

Figure 2. CH4 generation rates as functions of time estimated by the revised Afvalzorg model using site-specific waste input data (both Y axes apply to all curves). (Mou et al., 2014).

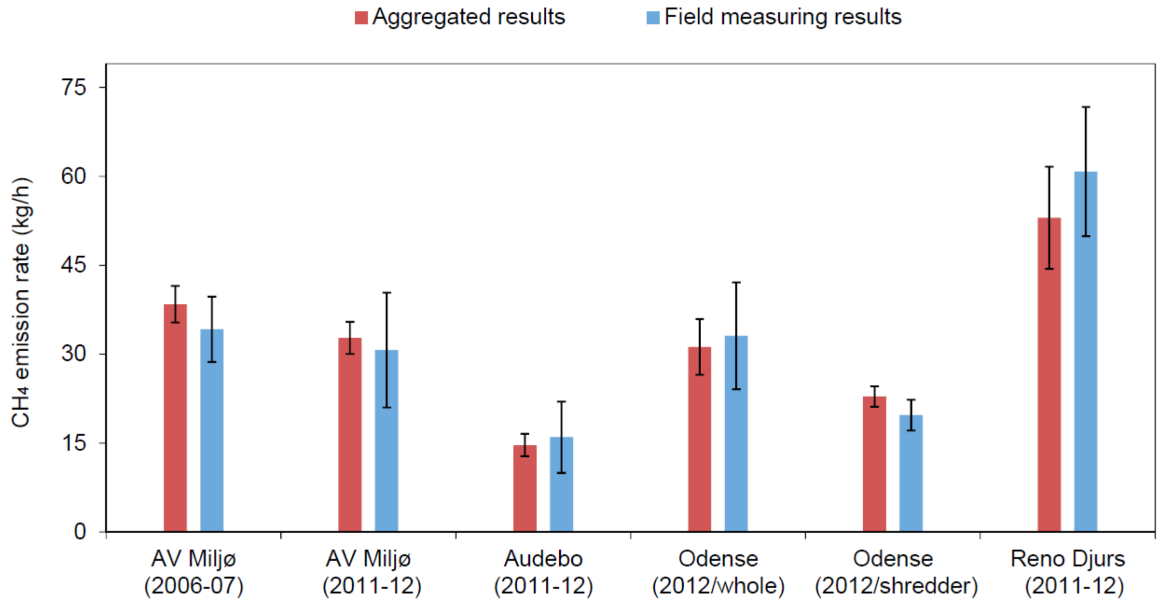

Figure 3. Comparison of aggregated fugitive CH4 emissions (kg hr-1) and measured wholesite CH4 emissions at four Danish landfills and one specific waste cell for shredder waste at the Odense landfill (Mou et al., 2014).

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